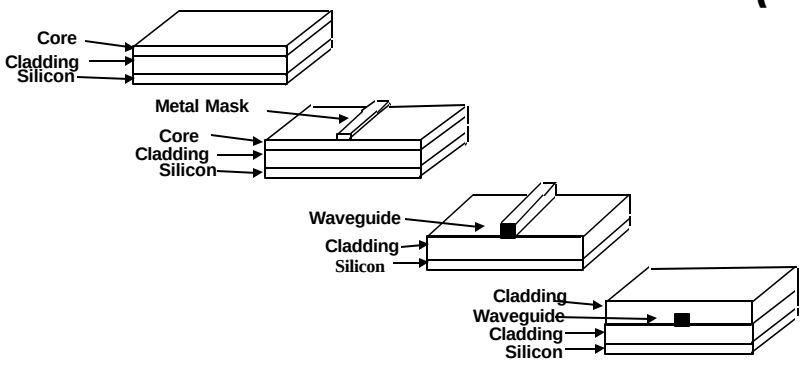
LIGHTWAVE MICROSYSTEMS

ATP - Optical Polymers for DWDM

LIGHTWAVE MICROSYSTEMS

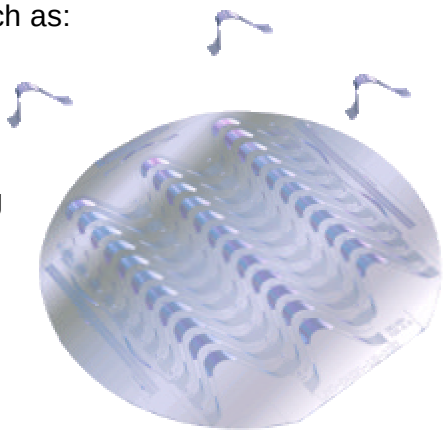
Planar Lightwave Circuits (PLC)



- Focus on Planar Lightwave Circuits
- Manufactured Using Semiconductor Processes
- Exploit Existing IC Manufacturing Technology
- Resources and Expertise from IC and Head Industries

Planar Lightwave Circuits

- Planar Lightwave Circuits Are The Next Generation
- Augment and Replace Discrete Components
- PLCs can provide functions such as:
  - Splitting
  - Coupling
  - Switching
  - Modulation
  - Wave Division Multiplexing
  - Add-Drop Functions
  - Phase Shifting
  - Variable Attenuation
  - Amplification
  - Filtering
  - Tapping
  - Dispersion Compensation



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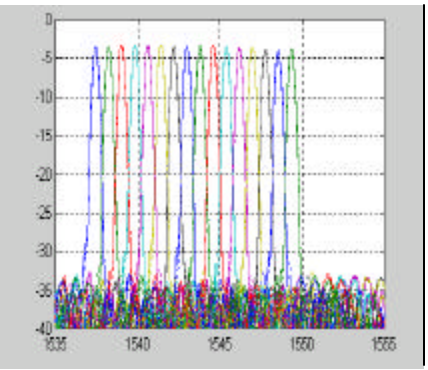
Lightwave Microsystems Background

- Design & Manufacture of Planar Lightwave Circuits
  - Semiconductor Methodologies
- Two Waveguide Technologies
  - Silica - AWG MUX/DMUX and Splitters
  - Polymer - Switches and VOAs
- End-End Capability
- Design
- 3000 sq.ft. Wafer Fab
  - Custom Designed and Built
  - 6” Wafers - Upgradable to 8”
- Pigtailing and Packaging
- Testing and Reliability

Arrayed Waveguide Gratings

- DWDM Filter - ITU Grid
- DMUX/MUX



- 8, 16, 32 and 40 Channels
- 200, 100 and 50GHz Spacing
- Potentially Lowest Cost/Port

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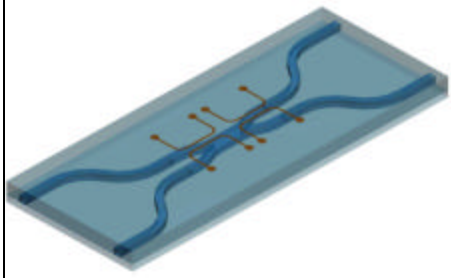
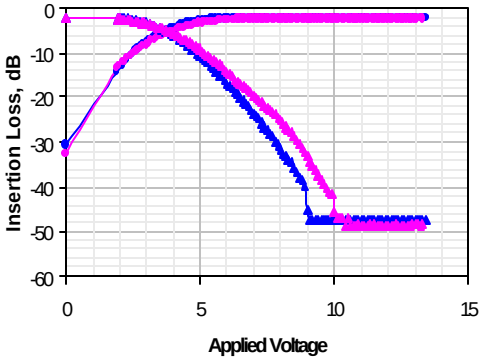
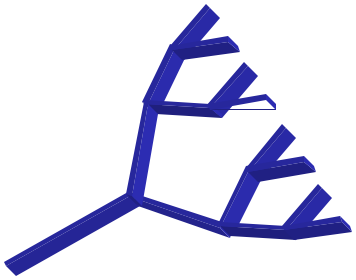
Integrated Optical Switches

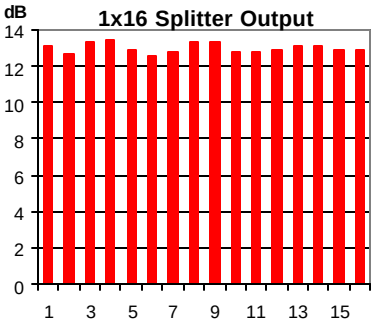




- Integrated Optical Switches Are Under Development
- 1 ms Switching Times Satisfy Most Network Needs
- Applications Include Add/Drop, Protection, Restoration

Fiber Optic Passive Splitters





- 8, 16 and 32 Ports
- Single Mode Fiber Splitters
- Compact Size
- High Uniformity

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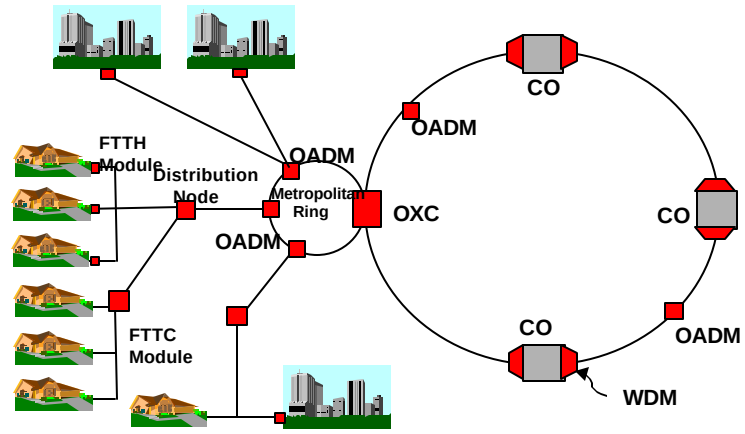
New Components Enable New Systems

- First Generation DWDM Systems Required
  - Precise and Stable Wavelength Lasers
  - Precise and Stable Filters
  - Fiber Optic Amplifiers
- Components Drive System Performance
  - 4 → 8 → 16 → 32 → 40 → 80 → 128 Channels
  - 400 GHz → 200 GHz → 100 GHz → 50 GHz Spacing
  - Better and More Precise Filters and Lasers
  - Better and More Precise Control over Amplifiers
- New Components Required for Next Generation Systems
  - Performance
  - Cost

"All Optical" Network

- In Whatever Form the "All Optical" Network Requires
  - More and Higher Performance Components
  - Lower Cost per Function
- The Number of Components Cannot Scale With The Number of Channels!
  - Arrays of Lasers
  - Arrays of Optical Switches
  - Arrays of Taps and Couplers
  - Arrays of Variable Optical Attenuators (VOAs)
  - Large Matrix Switches
  - Wavelength Translation
  - Semi-Custom Optical Circuits
  - Numerous Other Components/Functions

Enablers For Emerging Optical Networks



Optical Add/Drop Multiplexers (OADM) and Optical Cross-Connects (OXC)

Drivers For Integration

- As DWDM Systems Grow Component Counts Multiply
  Passive Count = (2xY)+2+(6xN)+1+(1+Y)*
  Y = Number of DWDM Channels
  N = Number of EDFA Repeaters
  e.g. For 80 Channels and 3 EDFA Repeaters
  → 261 Passive Components Required!
- Of Course Not All Components Are Equal
  - An 80 Channel DWDM is Complicated Indeed
  - Some Components Do Not Integrate Easily
- Integration of Some Components Can Reduce Cost
  - Manufacturing, Packaging and Assembly

*Example from W. Diamond, E-Tek Dynamics, 1999 OSA Executive Forum, San Diego, CA, Feb. 22, 1999:

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Target Products

- "Sub-Systems on a Chip"
- Dynamic Add/Drop Multiplexer
  - Allows Dynamic Network Configuration
  - Resource Allocation and Service Differentiation
  - Key Building Block for "All Optical Network"
- Optical Cross-Connect Switch (OXC)
  - Restoration
  - Network Management
  - Another Key Building Block

OADMs Will Fill Many Roles

- Static
  - Drop One or More Fixed Wavelengths
  - Require Physical Intervention to Provision (Truck Roll)
  - Most Common Current Deployment
- Partially Reconfigurable
  - Can Dynamically Drop Up To 25% of Channels
  - Must Predetermine Which Channels Can Be Dropped
  - Many Systems Announced
- Fully Reconfigurable
  - Dynamically Drop Any or All Channels
  - Most Flexible
  - Expected to be an Enabling Technology for Metro

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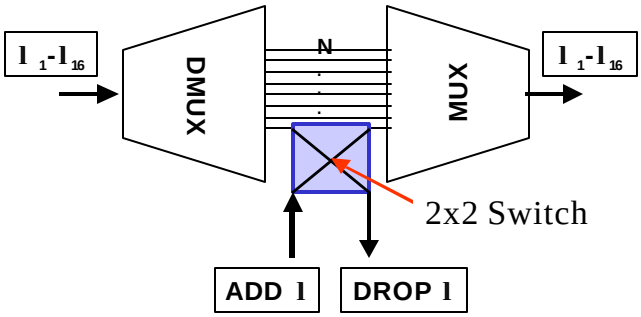
Components For Reconfigurable OADMs

- Many Components Required For Full Reconfiguration
  - DWDM DeMultiplexers
  - Optical Switches
  - Variable Attenuators
- The Number of Components Cannot Scale With The Number of Channels!
  - Integrated DWDM Filters
  - Arrays of Optical Switches
  - Arrays of Variable Optical Attenuators (VOAs)
- Packaging and Assembly Difficult at High Channel Counts

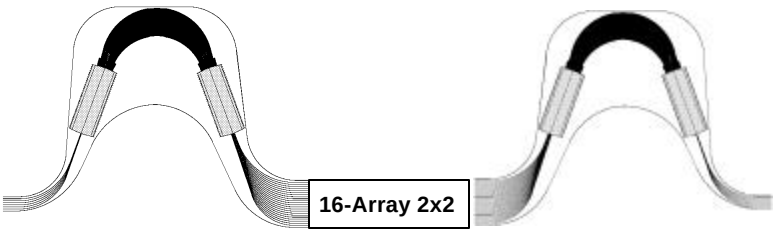
Example - OADM



16 Ch. Dynamic Optical Add/Drop Subsystem

- Requires 18 or More Discrete Components
- Requires 98 Fiber I/O and 66 Fiber Splices or More
- Integrated Version Requires Only 34 Fiber I/O and 34 Splices
- Enormous Savings In Packaging and Assembly Costs

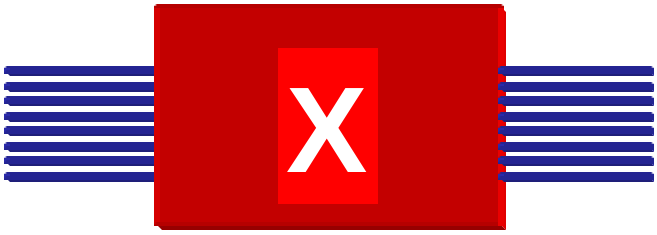
Fully Integrated OADM



- Fully Integrated OADM
- Most Efficient Manufacturing
- Most Efficient Packaging and Assembly
- Potential Improvements in Performance and Reliability

Optical Cross-Connect Switch

Highly Integrated Products Also Enable Optical Cross-Connect Switches



KEY PARAMETERS:

- **INSERTION LOSS**
- **BLOCKING / NON BLOCKING**
- **SPEED**

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OXC Status

- Emerging Optical Networks Require OXC Functionality
  - Restoration
  - Wavelength Routing
- No Current Technology Satisfies the Requirements
  - Equipment Vendors Forced to Use Electronic Alternatives
- Mechanical Switches Not Reliable or Compact Enough
- Numerous Emerging Technologies
  - MEMS
  - Liquid Crystal
  - Frustrated Total Internal Reflection
- Integration is the Key

Limitations of Optical Integration

- Many Challenges Remain for Optical Integration
- Different Materials Required for Different Functions
  - Some Materials Are Incompatible
  - Sometimes Only the Current Processes Are Incompatible
- Not All Functions Can Be Easily Integrated Together
  - Passive
  - Active
  - Non-reciprocal
- Integrated Technologies Are Still Being Developed
  - Manufacturing Issues
  - Reliability Issues
- The NIST ATP Program Addresses These Issues

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NIST ATP OVERVIEW

- NIST ATP funding enables the assembly of a critical mass of experts to attack challenging technical problems at an accelerated rate.
  - Polymeric materials having the necessary optical and physical properties.
  - Quality-driven manufacturing of polymer based devices.
  - Reliability of these materials in the chip form.
  - Packaging to ensure device performance that meets industry specifications.
  - Application specific device designs.
  - Evaluation of device and component performance in an actual network.

NIST ATP OVERVIEW

The Team

- Lightwave Microsystems Corporation - manufacturing, reliability, packaging, testing
- B.F. Goodrich - new material development and characterization
- Prof. Alex Jen, University of Washington/Northeastern University - new materials systems, optical characterization
- Prof. C.P. Wong, Georgia Institute of Technology - materials, packaging
- Prof. James Burke, University of Arizona - design, optics

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NIST ATP OVERVIEW

The Team (cont'd.)

- Dr. Michael Fryd, DuPont Fellow Ret. - polymer physics, polymer design, formulation, synthesis
- Prof. Gary Grimes, University of Alabama Birmingham and Lucent - component evaluation in networks
- Prof. R. Tweig, Kent State University - monomer and polymer synthesis
- Profs. Frank Harris and Stephen Cheng, University of Akron - high performance materials, characterization, processing

INTEGRATION OF NEW FUNCTIONS

- New Materials Allow Integration of New Functions
  - Electro-optic Materials for High Speed Switching
  - New More Compact Switches
- New Processes Allow Higher Functionality
  - Integration of Active Devices
    - Lasers
    - Detectors
    - Gratings
    - Circulators
- Higher Integration Reduces Packaging Costs
  - Hybrid Integration
  - Monolithic Integration

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NIST ATP OVERVIEW

- **The NIST ATP program allows us to develop our polymer switching technology which, when combined with our existing silica technology, will enable us to make highly integrated products for DWDM systems.**